Cooperative National Park Resources Studies Unit

ARIZONA

TECHNICAL REPORT NO. 22

HYDROLOGIC AND LIMNOLOGIC FEATURES OF QUITOBAQUITO POND AND SPRINGS, ORGAN PIPE CACTUS NATIONAL MONUMENT

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University of Arizona/Tucson - National Park Service

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INTRODUCTION

Objectives

The objectives of this study were to describe the basic limnologic and hydrologic features of the Quitobaquito Pond and spring system and to provide information that can be used to predict the long-term status of the ecosystem in the face of a variety of management plans. This study had two main emphases. First, to generate an approximate water budget for the system typical of an average day in midsummer. The purpose of this was to determine how critical the water supply is, how much of a decrease in supply could be tolerated without losing the pond, and to identify the natural components which are responsible for water loss from the system. The second main objective was to describe the limnologic dynamics of the pond ecosystem. Overall system metabolism was deduced from a study of physical and chemical characteristics. Importantly, these data were collected over a range of times during the year and during a single day in order to determine the range of states which the system might occupy. Results of this study were compared with past studies at the site, particularly the data collected by Professor Gerald Cole and his student, Mel Whiteside, nearly 25 years ago (Cole and Whiteside 1965).

Site Description

Quitobaquito Pond is a man-made impoundment formed by the flow of two, of several springs emanating from the Quitobaquito Hills in the Organ Pipe Cactus National Monument, near Lukeville, Arizona. The two springs flow approximately 100 m via a system of ditches to the 0.22 ha, 1 m deep pond. The pond outlet usually flows only a few meters and then seeps into the soil or is lost through evapotranspiration. Occasionally the pond outflow reaches into Mexico before disappearing. Figure 1 shows the Quitobaquito system.

The spring system, being one of the very few sources of surface water in one of the harshest deserts of North America, has a long cultural history and today represents a significant refuge for wildlife, including a variety of songbirds and waterfowl and the endangered pupfish, *Cyprinodon macularius*. The site is now protected and carefully managed by the U. S. National Park Service.

A more complete description of the Quitobaquito region can be found in Bennett and Kunzmann, (1989), Brown et al. (1983), Bryan (1925), Cole and Whiteside (1965), and Nabhan (1982).

METHODS

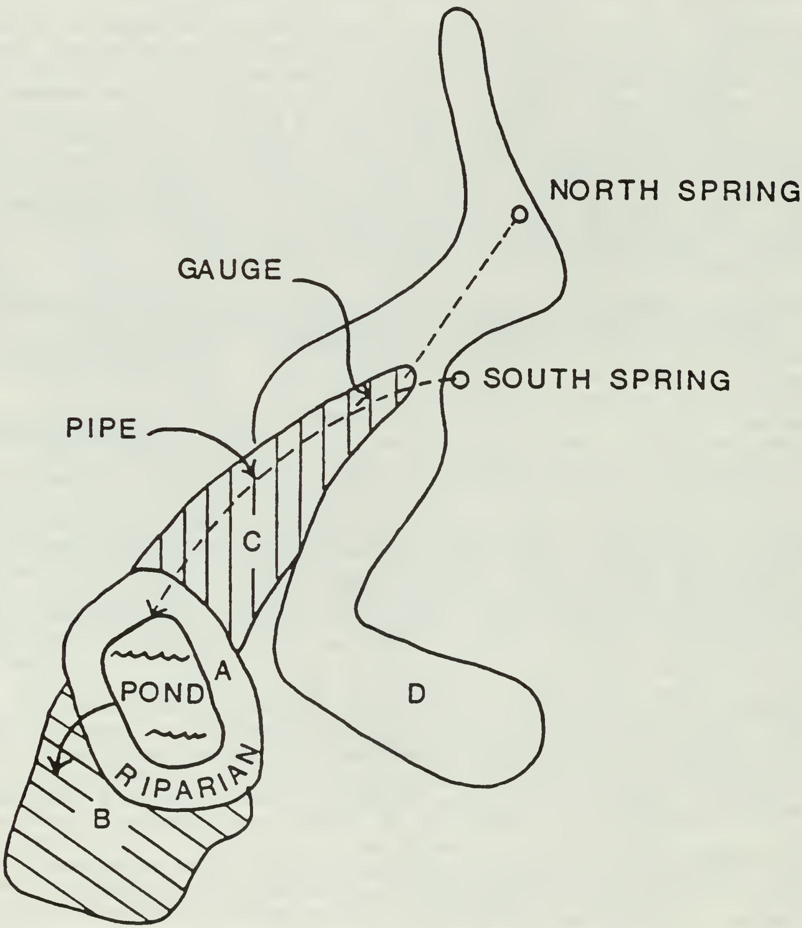
Field methods used in this study are standard limnological field techniques, many of which can be found in such references as Lind (1979) and Wetzel and Likens (1979). Chemical methods are derived from Golterman and Clymo (1969) and Hem (1970) modified for southwestern waters. Details of methods used are apparent from the text or provided and described in this section.

Samples were taken at Quitobaquito Pond, stream, or spring sites on five occasions from July 1984 to July 1986. On three of these dates, samples were taken at several sites and times. On two dates, samples were taken at irregular intervals over a 24-hour period. Streams and springs were sampled by hand using 250-ml polyethylene bottles. Pond samples were taken from a boat at a location near the center of the pond, where the pond depth was approximately 1.0 meter. Water samples from particular pond depths were taken by hand, in that the pond was quite shallow; however, oxygen samples were always collected with a suction device so as to avoid contact with the atmosphere.

Light measurements were made with a Protomatic photocell designed for limnologic work. Temperature was measured with a YSI thermistor system or a hand-held thermometer. Discharge was measured at the U.S. Geological Survey gauge (See Figure 1) by measuring the amount of water collected for a measured time internal. Stream flow was based on cross-sectional area and current velocity, the latter estimated by timed flotation. Long-term measures of discharge at the gauge were provided by the U. S. Geological Survey through Organ Pipe Monument offices.

Nearly all chemical measures were performed in the laboratory on samples which were transported on ice then filtered through Whatman GF/F glass fiber filters (pore size 0.7 um). Nitrate was determined by reduction to nitrite in cadmium-copper columns (Wood et al. 1967) and then measuring the resulting nitrite by a diazotization technique (Strickland and Parsons 1972). Ammonium was determined using the phenylhypochlorite method of Solorzano (1969). Total dissolved nitrogen was measured as nitrate and ammonium after four hours of ultra-violet oxidation (Manny et al. 1971). Soluble reactive phosphorus was measured colorimetrically (after Murphy and Riley 1962) and total dissolved phosphorus was determined as soluble reactive phosphorus after persulfate digestion. Conductivity was measured in the lab with a Markson model 10 conductivity meter and pH was determine using standard electrodes. Alkalinity was measured by titration with sulfuric acid. Chloride was measured titrimetrically with mercuric nitrate. Sulfate was determined turbidimetrically with mercuric chloride. Oxygen was measured by the Winkler technique or with an oxygen electrode (Leeds and Northrup).

Figure 1. Quitobaquito Pond and Spring system, Organ Pipe National Monument. This is a diagrammatic representation of the drainage sectors described in Table 3.



DISCHARGE OF QUITOBAQUITO SPRINGS

Water probably emerged historically in the Quitobaquito region over a broad area. Two sites have been developed and maintained and now presumably intercept the great majority of flow. North Spring flows through a small settling basin (See Figure 1), then through a 5 cm diameter pipe to its confluence with the outflow of South Spring. The combined discharge of these two springs is measured by a water-level recorder maintained by the United States Geological Survey. In mid-summer, each spring contributes equally to the flow at the gauging station. Once through the gauge, water is transported in a pipe to a small pupfish observation pool, and then to Quitobaquito Pond in a shallow, narrow, open channel.

Discharge measured at the gauge shows no evident seasonal trend and no response to precipitation events. Over the period October 1982 to February 1986, there was no long-term trend in discharge; however, there was a significant decline of about 4% per year from October 1983 to February 1986 ($p < 0.001$; See Figure 2). The range of discharge was quite small, ranging from 0.03 to 0.10 cfs (daily basis) over the period of record. Mean monthly flow is 0.072 cfs (2 1/s).

These data obviously should be examined over a longer time period in order to closely monitor long-term trends in discharge of these springs.

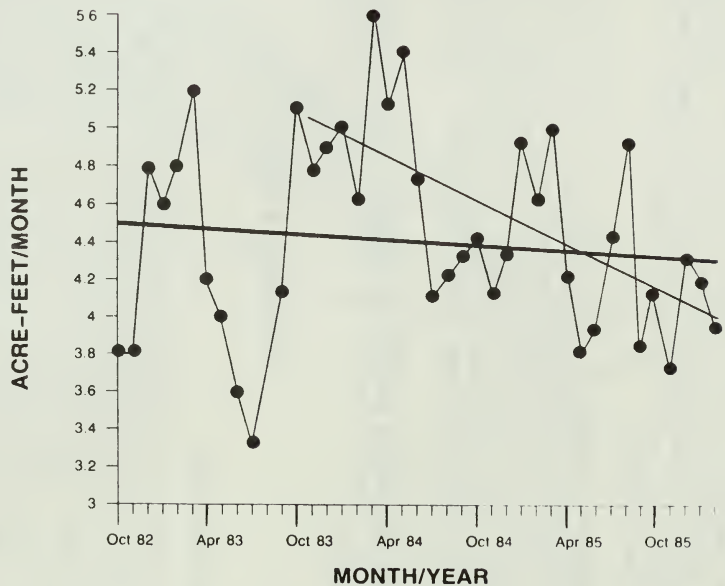
HYDROLOGIC BUDGET

Overview and Scope

Data collected allow estimation of the major terms of the input-output hydrologic budget for Quitobaquito Pond on a typical summer day. A water budget can be used to guide those management activities that involve modification of the water delivery system or that might result in diversion or alternative uses of water. In addition, a water budget provides a useful framework for viewing long term changes at Quitobaquito, for example to determine the influence, if any, of agricultural uses of water in the Rio Sonoyta drainage on Quitobaquito spring flow. It can be also used to anticipate the effect of increased phreatophyte growth over the decades on water loss through evapotranspiration. A water budget also is useful in determining the rate at which the pond level changes. This is particularly critical in protecting the important aquatic species present in the pond.

Midsummer was selected as the model period because this is when losses from the system through evaporation and transpiration are

Figure 2. Discharge of Quitobaquito North and South Springs, October 1982 to February 1986. Regression slope for this period is not significant; however, slope for October 1982 to February 1986 is significant at about 4% decline per year ($p < 0.001$).



highest. This is the most difficult period in which to manage the system for a positive water balance. It is also the time when interruption of water flow to the pond would result in the most rapid rate of drying of the pond. The idea in general is that if management works in July it will work for the rest of the year as well.

Units of input and output will be expressed here as centimeters of water over the area of the pond. For example, in a given day rainfall may add 2.5 cm to the pond (about an inch of rain) and stream flow may contribute another 7.5 cm for a total input of 10 cm per day. Since the pond usually remains level, output of water must balance this, e.g. 5 cm may leave via the outlet stream and 5 cm may be lost to the atmosphere by evaporation. For modeling purposes, the area of the pond was considered to be 2200 square meters (0.22 hectares or 0.54 acres) and the depth to be uniformly 1.0 meter. The volume was thus 2200 cubic meters (or 581,200 gallons).

Construction of a hydrologic budget involves description and quantification of inputs and outputs. Some of these flux terms are estimated from the literature (e.g. transpiration) while others are empirical (e.g. discharge at the gauging station).

A water budget must be for a spatially discrete system: in this case, the system is the pond, bank to bank, and surface to sediments. All of the water, soils, and vegetation in the Quitobaquito region is also a system that could be budgeted. In many ways this would be easier: input would be by spring flow from out of the ground (at a measured rate) and output would be by evapotranspiration. We would assume that for this site, all water emanating from the springs is lost to the atmosphere; that is, that there is no flow to the Sonoyta by surface or subsurface routes. If the area were denuded of vegetation (e.g. by fire or severe overgrazing) water equal to spring flow would be lost by evaporation alone. Plants would not be involved. As plants invaded and grew, an increasing percentage of loss to the atmosphere would occur through plants by transpiration, but the total combined amount of water lost (by evapotranspiration, ET) would be the same. In a sense, evaporation and transpiration compete for the same constant amount of input water. When the vegetation is fully developed, most water loss is through plants, by transpiration. At this time, if the flow of the springs were to increase, so would ET. If it decreased, so would ET. These changes in ET would occur through changes in the amount of vegetation present. A gradual loss of water would result in dying vegetation on the periphery of the plot, while an increase in water would expand vegetation.

It is important to note that plants at Quitobaquito as a whole do not cause a water loss in excess of spring flow, nor do they cause a water loss greater than would be generated by evaporation

were plants to be removed. Another subtle point: transpiration through plants does not exceed evaporation from an open water surface, or wet soil (Culler et al. 1982, Gatewood et al. 1950, Hansen 1984). Solar radiation provides the energy to evaporate water and the presence or absence of vegetation does not affect solar radiation. What plants can do, is extract moisture from below a dry soil surface which would otherwise provide for little evaporation. The important point is that with only slight exception, loss of water from a pond surface is the same as from a dense stand of plants in a saturated soil. The rate at which these occur is called potential evapotranspiration (Bowen 1982) which is in turn affected by the weather, and is very high in Arizona in July.

Since this budget is for the pond only, computation is more difficult. The management challenge is to get water through the pond sector before it is lost to the atmosphere. The problem is not to prevent water loss to the atmosphere-that is inevitable- but to influence where that loss occurs (preferably downstream from the pond).

Terms of the Hydrologic Budget

The following terms were evaluated to generate the summary budget:

INPUTS:
- Precipitation
- Stream (spring) flow
- Overland flow during storms
- Subsurface seepage

OUTPUTS:
- Evaporation (from pond surface)
- Subsurface seepage out
- Stream Outflow
- Transpiration (riparian plants)

Input: Precipitation

Precipitation records for Organ Pipe Cactus N.M. were used to estimate precipitation input for summer. These data were collected by the National Weather Service, covering the period 1944-1970, and have been published in Sellers and Hill (1974). These data are summarized for summer months in Table 1.

For budget purposes, 0.122 cm/d was taken as the best estimate of daily precipitation. Since actual rainfall obviously varies from day to day, a conservative budget might use 0.0 to consider drought periods, or simply, those days on which it does not rain.

Table 1: Summary of precipitation records for summer months in Organ Pipe Cactus National Monument.

Month	inches/month	inches/day	cm/d	summer mean (cm/d)
July	1.36	0.045	0.114	
August	1.79	0.058	0.147	0.122
September	1.23	0.041	0.104	

Input: Spring Flow

The combined flow of North and South springs is gauged by the USGS near the confluence of these spring streams. Flow varies from 0.03 cfs to about 0.10 cfs, with no apparent seasonal pattern (See Table 2). Mean summer flow is near 0.068 cfs, or 7.6 cm/d. This is a fairly conservative estimate of inflow; mean annual flow is 0.077 cfs or 8.65 cm/d. A portion of this water is immediately lost because the pipe between gauge and observation pool is of insufficient size to transport the total flow. Instead, about 21% spills into the old stream channel depression and is apparently lost to the atmosphere by evapotranspiration. In any event, it does not reach the pond. Correcting for this loss, the summary budget uses 6.00 cm/d as the spring flow input figure. Mean corrected flow for the entire year is 6.84 cm/d.

Input: Overland flow during storms

This input vector represents surface runoff from the small watershed into the pond during intense summer thunderstorms. It is very difficult to measure and is exceedingly sporadic and probably does not occur at all during some years. In the summary budget I estimate this to be zero.

It should be noted that while precipitation in the immediate vicinity of the pond and overland flow resulting from this may not enter the pond directly, this water is available for plant evapotranspiration and may reduce the demand for springwater which otherwise might be used for this purpose.

Input: Subsurface seepage

It is possible that some water seeps into the pond via subsurface routes. This water may be derived from the two main springs or from other associated but undeveloped springs at Quitobaquito. This is very difficult to measure or estimate by difference. For budget purposes, is assumed to be zero for the following reasons:

Table 2. Monthly mean instantaneous discharge, Quitobaquito Springs, AZ, in cubic feet per second (cfs). Data are from United States Geological Survey gauging station below confluence of North and South springs.

Month	1981	1982	1983	1984	1985	1986
January	-	0.037	0.075	0.081	0.080	0.07
February	-	0.055	0.086	0.081	0.082	0.07
March	-	0.063	0.085	0.090	0.08	-
April	-	0.061	0.070	0.086	0.07	-
May	-	0.058	0.065	0.087	0.06	-
June	-	0.062	0.060	0.079	0.07	-
July	-	0.064	0.053	0.067	0.07	-
August	-	0.064	0.048	0.068	0.08	-
September	-	0.063	0.070	0.072	0.06	-
October	0.048	0.063	0.083	0.084	0.07	-
November	0.046	0.064	0.080	0.069	0.06	-
December	0.041	0.077	0.080	0.070	0.07	-

a. Soil in the vicinity of Quitobaquito is very fine textured and subsurface transmission of water is likely to be low.

b. Excavated springs feeding the pond through the main surface channel are deeply cut into water-yielding strata and probably efficiently intercept seepage water, diverting it into the stream channel and pipe.

c. Minor, nearby seeps to the east of the pond provide water to the surface and obviously support substantial plant growth nearby. Dry strips between these seeps and the pond suggest that this water may be depleted locally by phreatophytes and is therefore not available for export to the pond. A summary of the input of water to the pond is shown in Table 3.

Table 3: Summary of estimated water inputs to Quitobaquito Pond, in cm/d.

Pathway	Moderate estimate	Conservative estimate (drought)
Precipitation	0.122	0
Spring flow	6.0	6.0
Overland flow	0	0
Subsurface seepage	0	0
Total	6.122	6.0

Output: Evaporation

Evaporation can be estimated by various mathematical formulations using solar insolation as the major independent variable; however pan evaporation is measured at many weather stations and can provide data for estimating pond evaporation rates. The data used here are from the Yuma Citrus Experiment Station, where pan evaporation is 264 cm/yr (104"). Pond and lake evaporation rates are lower than pan rates because the pan is usually warmer than the pond. Based on studies at Lake Mead, pond evaporation is about 39% of pan evaporation in winter and 84% in summer (Sellers and Hill 1974). Based on these modifications, evaporation from the pond surface at Quitobaquito is estimated at 0.84 cm/d in July and 0.59 cm/d annually. The former value was used in the budget.

Output: Subsurface seepage

This is not directly measurable but can be estimated by difference. For example, if water entering the pond exceeds that which is known to leave by all other routes, then the remainder

is assignable to seepage. There is reason to think this might be small. Vegetation rapidly thins below the pond toward Mexico, probably due to water limitation. Since most (79%) of the flow of the springs reaches the pond, we might reasonably expect at least as much vegetation below the pond as above. Aerial photographs reveal the opposite to be true. It is possible that water is lost straight down through the bottom of the pond at an angle so steep as to avoid interception by phreatophyte roots; however, given the lateral orientation of flow above the pond, this seems unlikely.

Output: Surface flow

The rate at which water leaves the pond through the outflow pipe is not known precisely. Clearly, better data are required on this parameter. In spring, I measured this to be nearly 70% of input. In summer, the water level less frequently rises to the level of the outflow pipe (although it apparently did so during midsummer 1985). To be conservative, outflow by this route is taken to be zero for purposes of the budget. Since this is downstream from the pond, water lost in this way can be considered "excess", indicating that the supply of water, less all other losses, is more than sufficient to keep the pond full. Problems arise only when the pond outflow is zero.

Output: Evapotranspiration

Evapotranspiration (ET) refers to water lost to the atmosphere before leaving the pond via deep seepage or surface outflow. Much of this is attributable to trees and shrubs that absorb water from bank storage at the pond periphery. In order to estimate this loss, two pieces of information are necessary: 1) the area of vegetation (e.g. m^2) drawing water more or less directly from the pond, and 2) the rate at which water is drawn by this vegetation.

Aerial photos were used to estimate the extent of heavy vegetation growth around the pond (See Figure 1). While these measurements are crude, they yield a riparian zone encircling the pond 40 m wide. As a more moderate estimate, a 15 m wide band was used based on the approximate height of the largest trees in the riparian zone. These two probably bracket the true value, which remains elusive. The more conservative value in the direction of water loss from the pond is 40 m, and will be used in these calculations.

The rate of ET per unit area is more easily estimated given the dense growth and saturated soils (by definition) at Quitobaquito Pond. These conditions allow us to apply to this area a rate of water loss estimated, to occur by evaporation, with slight

modifications. ET may be slightly higher than evaporation because: 1) interception of insolation exceeds that expected based on crown diameter because the vegetation on the periphery of the stand is not shaded and receives extra insolation when the sun is low in the sky; and 2) there is what is called an "oasis effect" in which warm air from the drier surroundings is drawn toward the cooler stand by advection (wind), enhancing evaporation from leaf surfaces (Hansen 1984).

To be conservative in the direction of water loss from the system, pond evaporation (0.84 cm/d) is multiplied by 1.2 to describe loss of water from the dense vegetation, yielding an estimate of 1.0 cm/d. This is a high rate and is clearly an overestimate for peripheral areas at Quitobaquito where soil is relatively dry and actual transpiration is undoubtedly lower than 1.0 cm/d. However, this estimate compares favorably with published results; Saltcedar and Seepwillow in the Safford Valley, 1.21 and 0.79 cm/d, respectively, and 0.99 cm/d for Cottonwood in California (Robinson 1958).

The units used to describe evapotranspiration here are to be applied to the terrestrial vegetation; however, for construction of the budget, these same rates are reported per unit area of the pond. Since the land area involved is greater than the pond area, budget rates are larger numbers than actual terrestrial rates. These relationships are explicated in Figure 1 and Table 4.

Table 4. Area (m^2) and estimated evapotranspiration (ET) loss from watershed subsystems at Quitobaquito, illustrated in Figure 1. ET rates are in cm/d expressed over pond area and are based on ET rate of 1.0 cm/d in terrestrial sector in July.

Sector	Area	ET
Pond	2,200	0.84
A40	11,693	5.32
A15	3,210	1.46*
B	5,131	2.33
C	4,478	2.04
D**	17,206	(7.74)
A40 + B + C	21,302	9.68

*A15 is part of A40.
**Sector D is assumed not to contribute to the pond.

Water flowing past the gauge may be lost by evapotranspiration in Sector C above the pond, in the Riparian Zone (A40) or in Sector B below the pond. Given the 21% leak at the gauge, and the fact

that the rest of the water flows to the pond in a pipe, Sector C can be ignored as an output from the pond. In the total output summary, outflow is taken to be zero and the 40 meter wide riparian band is considered to be the only output vector from the pond by ET. If and when pond outflow occurs, Sector B is watered and transpires this outflow fraction to the atmosphere. As in all these estimates, changes in soil moisture storage, vagaries of the weather, and other factors cause time lags and complicate the picture presented here, but they do not change its essential features. Based on these considerations, evapotranspiration is estimated to be 5.32 cm/d and is wholly attributed to Sector A40 (see Figure 1 and Table 4).

An independent check on evapotranspiration can be empirically estimated at Quitobaquito based on the following observations and assumptions:

1) 21% of the mean summer flow leaks from the pipe and enters sector C. This is, on the average, 1.6 cm/d in summer.

2) Assume all of this water is lost to the atmosphere by ET.

3) ET for sector C is thus 1.6 cm/d over an area of 4478 m2.

4) Assume the rest of the vegetation (sectors A + B) transpires at the same rate per unit area.

5) Evapotranspiration for Sector A + B = (16,824 m^2/4478 m^2) x 1.6 cm/d = 6.01 cm/d.

This empirical value for ET from the riparian (6.01 cm/d) agrees well with the rate calculated based on the theory (5.32 cm/d). Since most of Sector B is not saturated with water, as the model assumes, actual agreement is probably better than shown above. It is important to remember that these rates are all in "pond" units and do not relate to ET per unit forest area. In fact, Sector C apparently transpires water at a rate of 0.79 cm/d. Theory suggests this should be 1.0 cm/d, likewise, a fairly close agreement. Table 5 summarizes output of water from the pond.

Table 5: Summary water budget estimates of outflows from Quitobaquito Pond, in cm/d.

Pathway	Conservative Estimate
Evaporation from pond surface	0.84
Evapotranspiration	5.32
Subsurface seepage	0.00
Surface Outflow	0.00 (assumed, actually sporadic)
TOTAL OUTPUT	**6.16**

Budget Summary

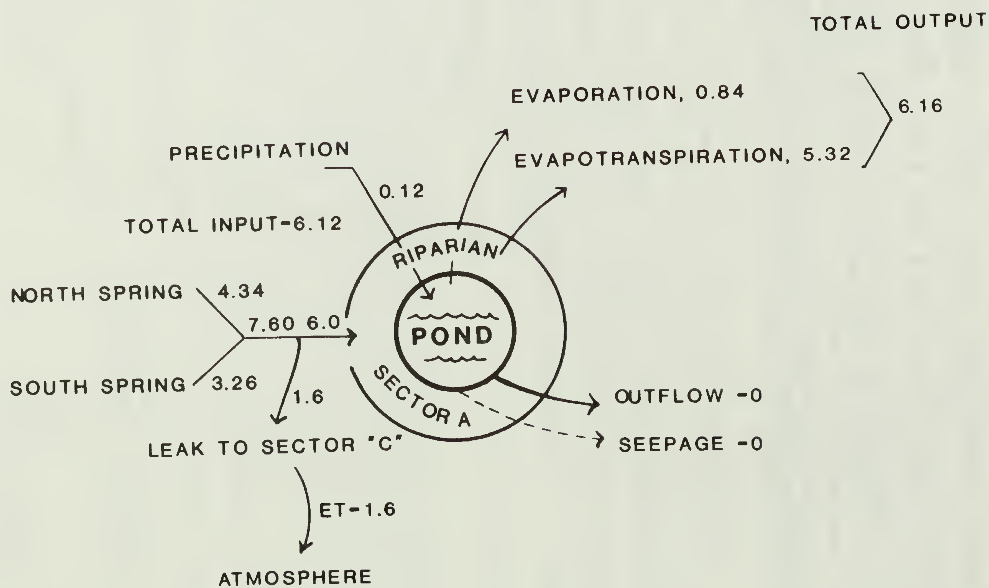
The budget balances very closely in spite of its conservative assumptions and independent method of calculation. This is illustrated in Figure 3, but the basic equations are as follows:

INPUT = PRECIP + SPRING FLOW = 0.12 + 6.0 = 6.12 cm/d

OUTPUT = EVAP (pond) + ET = 0.84 + 5.32 = 6.16 cm/d

Subsurface seepage (in and out) and storm runoff are considered to be zero for purposes of this model. Seepages are in actuality, probably small and storm runoff is sporadic and small. Storm runoff likely contributes to and is in part responsible for the maintenance of Sector B, in that storm flow is probably rapidly routed through the pond and out the outflow pipe.

Figure 3. Water budget of Quitobaquito Pond for a typical midsummer day. Data in cm/d with respect to pond area.



LIGHT

Light was measured at incremental depths in Quitobaquito pond to determine the extinction characteristics of the water. Transmission characteristics of Quitobaquito water vary substantially through the year (See Table 6). The extinction coefficient, K, describes the extent to which solar insolation is absorbed by the water column. K ranges from 0.68 to almost 4.0, with lowest values (clearest water) in March and April.

Clarity of the water can also be described in terms of the depth at which some percentage of surface light is extinguished (See Table 7). Ninety percent of surface light was absorbed in the first 0.58 m in July 1984, but in March 1985, 3.38 meters of water would be required to absorb a comparable percentage. This measure is of course hypothetical, as maximum depth of the pond is just 1.2 meters.

A third measure of light penetration is the percentage of light energy remaining at a depth of 1.0 m (the approximate average depth of the pond). These dates are shown as % at 1 m in Table 6. In March 1985, 39% of light reached the bottom while in July 1984 only 1.4% of light remained.

July 1984 values in both Table 6 and Table 7 correspond to a situation where the pond bottom was not visible at 0.9 m to an observer in a boat. In July 1985 on the other hand, the bottom was faintly visible; however, in March and April the bottom was clearly visible and the water could be described subjectively as very clear. Transmission characteristics of aquatic ecosystems greatly influence rates of photosynthesis, particularly of benthic plants. As a rule of thumb, 1% of ambient (surface) light is required for photosynthesis (P) to exceed respiration (R) (Wetzel 1983). The point at which P = R is called the compensation point, below which more oxygen is used by respiration than is generated by photosynthesis. Except for July 1984, the bottom of the pond was always well above the compensation point. In July 1984, the bottom coincided with the compensation point. This rule of thumb is a rough one. Light reaching a given depth obviously varies through the day and is zero at night. Still, these data clearly suggest that photosynthesis is probably not light limited anywhere in the pond, even when the water is so turbid as to render the bottom invisible from the surface.

Light extinction can result from dissolved and/or suspended substances in the water. Dissolved substances such as humic acids color the water and render it a murky brown (Hem 1970). Colored water is typical of acid bogs of the northeastern U.S. There is no evidence that Quitobaquito waters are colored. On the platinum-cobalt scale, color is below measurable limits.

Table 6. Light reaching selected depths in Quitobaquito Pond. Light readings are in foot-candles; depth in cm. K is the extinction coefficient for the entire water column. Also shown are z, 10%, which is the depth in at which 10% of surface light remains, and % at 1 m the percent light present at 1.0 meters depth.

	Date			
Depth (m)	7/26/84	3/11/85	4/18/85	7/30/85
0.0	5600	1650	520	4800
0.1	-	-	-	4350
0.2	-	1550	450	4000
0.3	1900	1483	420	3800
0.4	-	1366	380	3400
0.5	810	1283	350	2800
0.6	-	1162	340	2500
0.7	340	1083	320	2300
0.8	250	962	-	-
0.9	-	-	-	-
k	3.99	0.68	0.69	1.06
z, 10%	0.58	3.38	3.33	2.17
% at 1 m	1.4	39	37	6

Table 7. Percent of surface light present at different depths in Quitobaquito Pond on four dates, 1984-85.

	Date			
Depth	7/26/84	3/11/85	4/18/85	7/30/85
0.0	100.0	100.0	100.0	100.0
0.1	-	-	-	90.6
0.2	-	93.9	86.5	83.3
0.3	33.9	89.9	80.8	79.2
0.4	-	82.8	73.1	70.8
0.5	14.5	77.8	67.3	58.3
0.6	-	70.4	65.4	52.1
0.7	6.1	65.6	61.5	47.9
0.8	4.5	58.3	-	-
0.9	-	-	-	-

Particulate substances which are responsible for light extinction in Quitobaquito Pond may be either living or non-living. Light extinction and reduced visibility in July 1984 was attributable to fine inorganic materials which had been washed into the pond by overland flow generated by intense thunderstorms in the days preceding sampling. In July, 1985, particulates were largely organic, consisting of diatoms and an amorphous, apparently organic floc. This material formed a dense layer 10 to 20 cm above the bottom, which caused rapid extinction of light when the photosensor was lowered into it.

Perhaps the most significant findings associated with light measurements at Quitobaquito can be summarized as follows: 1) water clarity varies widely from crystal clear to highly turbid; 2) turbidity is a function of both watershed-derived inorganic particles and organic particles generated in situ; 3) light is not likely to limit primary production in this shallow pond.

Cole and Whiteside (1965) did not formally measure light extinction characteristics of the pond in 1964, but they report turbidity of the pond to be substantially higher than in the springs, where turbidity was zero. Pond turbidity was 140 units in 1964 compared to 112 units on 7/29/84, when light extinction (k) was 3.99 and the bottom was not visible at the 1.0 meter depth. While turbidity was measured only on this one date, pond water was substantially clearer on all other study dates, as K values attest (See Table 6). Water with turbidity in the range 50-200 is considered to be "intermediate", with "muddy" above and "clear" below this range (McKee and Wolf 1969).

TEMPERATURE

Temperatures of springs and streams connecting springs with the pond are relatively constant through the year (Table 8). South Spring, for example ranges from about 24.8° C in March to 29.3° C in July. Cole and Whiteside (1965) reported 23.9° C for spring water in May 1964 and 27.8° C the previous June. This is a narrow temperature range, especially considering that there was no attempt to record temperature exactly where water first emerged from the ground. In winter, water cools as it flows to the pond, while in summer it warms. As a result, the pond shows a much greater temperature range than the spring system; about 17° to 33° during the dates of this study (see Table 9). This range might have been even wider had recordings been taken continuously.

The pond shows a very interesting vertical temperature profile, which is best illustrated in July 1984. At 1400 hours the pond was thermally stratified (See Table 9) with temperature ranging from 33° C at the surface to 27° C at the bottom. Cole and Whiteside (1965) reported a 1.1° C temperature range in

Quitobaquito Pond in May 1964. It is somewhat unusual for ponds as shallow as Quitobaquito to exhibit thermal stratification because mixing by wind action is so easy in shallow lakes. However, thermal stratification is more readily attained in desert ponds because the temperature is so high. The density difference between 27 and 33 °C (a 6 degree range) is equivalent to the density difference associated with a temperature difference from 4° C to 20° C (a 16 degree difference) (Hutchinson 1957). Since it is the density difference that confers stability of stratification (resistance to mixing by wind action), not the temperature difference itself, shallow ponds in deserts are much more likely to stratify than ponds of temperate zones of the same morphometry.

Thermal stratification disappeared overnight in Quitobaquito Pond, however, as loss of heat to the atmosphere lowered the surface temperature to that at the bottom (See Figure 9). Surface cooling usually generates vertical convection currents (as cool water sinks). This mixes the lake from top to bottom during the night, even in the absence of wind. On windy days (July 1985) stratification may be weak or absent as the density difference generated is insufficient to resist vertical mixing.

The pattern in which a lake stratifies, then mixes under isothermal conditions several times during a year is termed polymixis (Cole 1983). Quitobaquito probably stratifies and mixes every day in summer (sometimes more than once) and probably does so on calm days in winter as well. Quitobaquito is thus polymictic. Most lakes mix only once or twice per year. At the latitude and elevation of Organ Pipe National Monument, deeper lakes would be expected to be warm monomictic lakes. That is, they remain stratified all summer and turn over (mix) just once, in winter. Most of the lakes and large reservoirs of low elevation regions of the Southwest are warm monomictic (Hutchinson and Loffler 1956).

The pattern of stratification exhibited by a lake has a profound effect on life in that ecosystem and on water chemistry, which is influenced greatly by interactions with the biota. Interactions between thermal stratification and water chemistry at Quitobaquito will be discussed in the following section.

WATER CHEMISTRY

Water chemistry determinations conducted in this study focused on anions, particularly those forms of nitrogen and phosphorus likely to limit biological productivity in these systems. Each set of parameters will be discussed in turn below.

Table 8. Water temperature at selected sites in the Quitobaquito spring-stream ecosystem, 1984-1985.

Date	Site	Time of Day	Temp °C
3/11/84	Pond Surface	1700	19.9
	North Spring	1555	26.3
	South Spring	1546	24.8
	Gauge	1540	25.6
	Observation Pool	1520	25.4
	Inlet to Pond	1510	25.3
4/18/84	Pond Surface	1330	24.3
	North Spring	1200	27.2
	South Spring	1216	26.6
	Gauge	1153	26.9
	Observation Pool	1410	26.9
	Inlet to Pond	1415	26.9
7/30/85	Pond Surface	1200	32.5
	South Spring	1220	29.3
	Gauge	1230	29.7
	Observation Pool	1239	31.6

Conductivity and Major Ions

Conductivity, or specific conductance, is a measure of total dissolved ions in solution. Values approach near 1000 uS/cm in the springs and range from 812 to over 1200 uS/cm in the pond (Table 10). These values are typical of alkaline western waters and are characteristic of water suitable for irrigation (McKee and Wolf 1963). There is no appreciable seasonal difference in conductivity of spring or pond samples and no evident diel variation in the pond.

Conductivity is usually a conservative measure of water chemistry and, because it is largely due to elements in great excess relative to organismal fluxes, varies little with time. Major contributors to conductivity are the anions sulfate, chloride, and probably bicarbonate. The major cation is sodium, with calcium, magnesium and potassium low and coequal (Peter Bennett, National Park Service, unpublished data). While Cole and Whiteside did not measure conductivity in 1963 or 1964, they report total dissolved solids (TDS) between 808 and 1344 mg/l, TDS in mg/l usually corresponds to 50-90% of conductivity measured in uS/cm. Using this conversion factor, TDS in Quitobaquito Pond during 1984-85 could have ranged from as low as 363 to as high as 1100. While it is difficult to compare data

Table 9. Water temperature at Quitobaquito Pond at selected dates, times and depths. Depths in m; temperature in °C. 1984-85.

	DATE									
	7/26/84		7/27/84	3/11/85		3/12/85	4/18/85		7/30/85	
	TIME									
DEPTH	1400	1700	0700	1345	1400	0905	1120	1330	1130	1300
0.01	33.0	-	-	-	-	-	-	-	-	-
0.1	33.0	31.7	27.7	19.7	19.7	17.4	18.5	24.3	31.8	33.1
0.2	32.0	30.3	27.7	19.7	-	-	-	24.3	31.8	-
0.3	30.1	28.9	27.7	-	-	-	-	24.3	31.7	-
0.4	29.1	27.5	27.7	-	-	-	-	24.3	-	-
0.5	28.6	28.1	27.7	19.7	19.7	17.4	18.5	24.3	31.7	32.8
0.6	27.6	27.6	27.7	19.7	-	-	-	24.3	-	-
0.7	27.5	27.6	27.7	-	-	-	-	24.3	31.2	32.8
0.8	27.2	27.6	27.7	19.7	19.7	17.4	18.5	24.3	31.8	32.8
0.9	27.1	27.6	27.7	19.7	-	-	-	-	31.0	32.8
1.0	27.2	27.5	27.7	-	-	-	-	-	-	-

derived from different sites and methods, these data suggest no significant changes in bulk water chemistry at Quitobaquito during the last 20 years.

pH and Alkalinity

The measure of hydrogen ion concentration is pH and the measure of the buffering capacity of the water is alkalinity. pH ranged from less than 8.0 in the springs to almost 10.0 in the pond in July 1985. Alkalinity exhibits the reverse pattern, decreasing from springs to pond in July 1985 (See Table 10).

Alkalinity and pH are related in a way that explains this mirror image. Groundwater is often supersaturated with dissolved CO_2, enabling subsurface water to dissolve large amounts of carbonate, which is otherwise sparingly soluble at pH up to about 10. When springwater emerges at the surface, alkalinity (largely due to $CaCO_3$) is high and pH (due to dissolved CO_2) is low. As carbon dioxide escapes to the atmosphere, pH rises and alkalinity drops. This is usually accompanied by precipitation of calcium carbonate. If this precipitation occurs in the water column and then settles to the bottom, the resulting deposit is called marl. If the deposit occurs directly on surfaces, the carbonaceous deposit is called travertine. Photosynthesis removes CO_2 from solution also and can be instrumental in precipitating carbonates (as marl if phytoplankton are involved, or as travertine if benthic, periphytic algae are the photosynthesizers). Data of Bennett (National Park Service, unpublished) show that calcium in spring water is substantially higher than calcium in pond water, supporting the hypothesis that $CaCO_3$ precipitation is occurring in Quitobaquito Pond, whether the mechanism be biologic (associated with photosynthetic removal of CO_2) or abiotic (resulting from escape of CO_2 to the atmosphere).

A further line of evidence supporting the precipitation hypothesis comes from analysis of shallow cores of the pond bottom. Pond sediments are highly compacted, white in color, and extremely reactive to applied acid, indicating that they are largely carbonaceous. This material may have been generated in situ as described above; however, transport from the watershed during storm events may also have contributed to these deposits. Pond sediments will be discussed more fully in a later section.

Table 10. Selected chemical characteristics of Quitobaquito Pond, Spring, and stream water at various times and dates, 1984-85. (COND=specific conductance, uS/cm; TURB=turbidity, NTU; TALK=total alkalinity, meq/l TDN=total dissolved nitrogen; TDP=total dissolved phosphorus; OXY=dissolved oxygen. All concentration units in mg/l=ppm unless otherwise specified).

DATE	SITE	TIME	DEPTH	TEMP	COND	TURB	pH	TALK	CL	SO4-S	NH3-N	NO3-N	TDN	PO4-P	TDP	OXY
5/24/64*	Pond	1430	1.0m	31.1	-	140	7.7	4.11	383	100	-	0.007	-	0	-	5.6
7/26/84	Pond	1400	0.1	33.0	865	-	9.2	3.39	134	95	0.018	0.53	0.86	0.037	0.038	-
7/26/84	Pond	1400	0.5	28.6	872	-	9.3	3.45	136	94	0.015	0.52	0.85	0.029	0.032	-
7/26/84	Pond	1700	0.1	31.7	845	-	9.3	3.39	133	90	0.019	0.54	0.87	0.033	0.037	-
7/26/84	Pond	1700	0.5	28.1	872	-	9.2	3.65	136	101	0.012	0.66	0.92	0.027	0.03	-
7/27/84	Pond	0700	0.1	27.7	812	-	9.3	3.48	133	100	0.027	0.54	0.93	0.032	0.034	-
7/27/84	Pond	0700	0.5	-	830	-	9.2	3.49	134	98	0.029	0.56	0.9	0.032	0.031	-
7/29/84	Pond	1000	0	-	725	112	8.8	3.17	106	-	0.04	0.51	0.96	0.051	0.056	-
3/11/85	Pond	1400	0.1	19.7	950	-	8.7	-	-	-	0.036	0.95	-	0.005	-	13.7
3/11/85	Pond	1400	0.5	19.7	900	-	8.65	-	-	-	0.07	0.98	-	0.005	-	13.75
3/11/85	Pond	1415	0.1	-	950	-	8.6	-	-	-	0.043	1.08	-	0.005	-	13.2
3/11/85	Pond	1415	0.1	-	950	-	8.6	-	-	-	0.056	0.99	-	0.004	-	-
3/11/85	Pond	1415	0.1	-	950	-	8.7	-	-	-	0.036	0.95	-	0.005	-	13.7
3/11/85	Pond	1415	0.1	-	875	-	8.65	-	-	-	0.043	0.97	-	0.007	-	-
3/11/85	Pond	1415	0.1	-	950	-	8.65	-	-	-	0.028	1.23	-	0.005	-	-
3/11/85	Pond	1700	0.1	19.9	900	-	8.75	-	-	-	0.033	1.13	-	0.004	-	14.5
3/11/85	Pond	1700	0.5	19.9	900	-	8.7	-	-	-	0.055	1.13	-	0.008	-	-
3/12/85	Pond	0905	0.1	17.4	900	-	8.65	-	-	-	0.073	1.07	-	0.006	-	11.4
3/12/85	Pond	0905	0.5	17.4	900	-	8.66	-	-	-	0.043	1.11	-	0.004	-	-
3/12/85	Pond	1120	0.1	18.5	1000	-	8.25	-	-	-	0.059	0.95	-	0.005	-	12.1
3/12/85	Pond	1120	0.5	18.5	1000	-	8.55	-	-	-	0.05	0.92	-	0.005	-	-
4/18/85	Pond	1330	0.1	24.3	1000	-	9.6	-	-	-	0.007	0.38	0.49	0.005	-	12.8
4/18/85	Pond	1330	0.8	24.3	1000	-	9.5	-	-	-	0.004	0.38	0.46	0.005	-	12.8
7/30/85	Pond	1130	0.2	31.8	1210	-	9.42	4.3	-	-	0.01	0.261	0.51	0.05	-	9.7
7/30/85	Pond	1130	0.7	31.2	1200	-	9.7	4.45	-	-	0.006	0.276	0.53	0.004	-	12.6
7/30/85	Pond	1335	0.2	-	1200	-	9.8	4.39	-	-	0.01	0.245	0.49	0.004	-	-
5/24/64*	Spring	-	-	23.9	-	0	8.2	4.02	318	91	0.09	2.25	-	0	-	-
7/26/84	No. Spr	-	-	-	923	-	7.9	5.33	143	105	0.014	2.78	2.94	0.004	0.006	-
	So. Spr	-	-	-	965	-	7.9	5.25	140	109	0.02	2.76	2.88	0.003	0.005	-
	Obs. Pool	-	-	-	984	-	7.9	5.3	141	102	0.016	2.62	2.6	0.002	0.004	-
	Pond Inlet	-	-	-	1000	-	7.9	5.3	145	-	0	2.58	2.62	0.006	0.008	-
4/18/85	No. Spr	1200	-	27.2	925	-	8.1	-	-	-	0.02	3.14	2.85	0.008	-	8.0
	So. Spr	1216	-	26.6	950	-	7.9	-	-	-	0.037	3.18	2.78	0.005	-	8.3
	Gauge	1153	-	26.9	950	-	8.1	-	-	-	0.018	3.17	2.78	0.004	-	7.4
	Obs Pool	1410	-	26.9	925	-	8.1	-	-	-	0.01	3.16	2.69	0.004	-	7.7
	Inlet	1415	-	26.9	925	-	-	-	-	-	0.006	3.06	2.68	0.004	-	8.1
7/30/85	No. Spr	1216	-	-	1050	-	8.7	-	-	-	-	-	-	0.01	-	-
	So. Spr	-	-	29.3	1100	-	8.4	-	-	-	-	-	-	0.005	-	6.1
	Gauge	-	-	29.7	-	-	-	-	-	-	-	-	-	-	-	7.0
	Obs Pool	1239	-	31.6	1050	-	8.21	5.53	-	-	0.008	2.76	2.72	0.007	-	6.9

*Cole and Whiteside (1965)

Nitrogen

Nitrogen was measured in three main forms during this study: ammonium, nitrate, and total dissolved nitrogen (TDN), which includes ammonium, nitrate, and dissolved organic nitrogen. Since TDN includes NH_3 and NO_3 but is determined as a separate analysis, data indicating TDN less than $NH_3 + NO_3$ are erroneous and represent experimental error. TDN at springs is consistently high (near 3 mg/l) and is largely NO_3. Ammonium-N is very low, usually less than 20 ppb. Little change in nitrogen species occurs in the spring-stream system, but a striking change occurs in the pond. TDN in Quitobaquito Pond ranges from 0.25 to 1.2 mg/l, with lowest values in summer. These values are only 10 to 35% of those in input water, indicating substantial removal of nitrogen, probably by the biota. Ammonium shows a similar seasonal pattern, with low concentrations in summer; however, except in July 1985, pond NH_3 is higher than spring stream NH_3, probably reflecting net mineralization of TDN. Nitrate however, shows a marked reduction between spring and pond, suggesting NO_3 uptake.

Rapid NO_3 uptake has been documented in other southwestern aquatic ecosystems (Grimm et al 1981, Grimm and Fisher 1986) and was reported for Quitobaquito 24 years ago by Cole and Whiteside (1965). Loss of NO_3 from the water column may be attributed to photosynthetic plants or to denitrifying bacteria. The latter convert NO_3 to N_2 or N_2O gas, which are then lost to the atmosphere. Uptake by photosynthesizers represents not a loss but a transformation and this nitrogen would still remain in the pond albeit in another ecosystem compartment (e.g. the sediment or the riparian vegetation). Alternatively, nitrogen sequestered by vegetation could be exported from the ecosystem for example, through harvesting, or by grazing by wildlife or cattle on riparian vegetation.

There is no way to sort out these alternatives with the data at hand. Grimm and Fisher (1986) attributed nitrogen disappearance in a desert stream to photosynthetic uptake by algae (which were subsequently exported downstream during floods). However, that stream was well oxygenated and anoxic zones where denitrification could occur were rare. Quitobaquito Pond is quite anoxic below the sediment-water interface and could support substantial denitrification.

The details of the nitrogen cycle in this ecosystem are of more than academic interest. The nitrogen supply to the pond is finite and occurs via the spring system. Reduction in nitrate concentration is rapid, and while limiting concentrations were never reached during this study, only a small percent change in photosynthesis (or denitrification) could generate these conditions. Cole and Whiteside (1965) report limiting nitrogen in the pond during their study. A similar situation could occur today, but simply did not on the days samples were taken.

Dynamics of the limiting nutrient control the rate at which photosynthesis occurs, and ultimately, the rate at which the pond fills with organic matter. As light is probably not limiting in this shallow ecosystem, productivity is likely to be potentially limited by a nutrient.

Phosphorus

Phosphorus is reported in two forms: total dissolved phosphorus (TDP) which includes all inorganic and organic forms, and PO_4-P. The latter is thought to be readily used by autotrophic organisms during photosynthesis, while dissolved organic phosphorus is more recalcitrant and is less readily used. Most of the phosphorus in both pond and spring systems is present as inorganic PO_4, but at low concentrations. Phosphorus has also been implicated as a limiting nutrient in lakes and streams (Likens 1972, Schindler 1977). However, in regions of historic volcanism, phosphorus in rocks is usually sufficiently high to prevent PO_4 depletion, even under conditions of rapid uptake (Grimm and Fisher 1986). Phosphorus dissolves from parent minerals (largely calcium phosphate) as fast as it is removed from solution by algae. In July, 1984, phosphorus was much higher in the pond than in the spring. One year later, however, no significant difference in phosphorus between pond and springs was evident. The important observation here is that phosphorus is low but detectable in springs and pond at a time when nitrogen is rapidly lost. Since one would expect nitrogen and phosphorus to be taken up at a stoichiometric ratio of approximately 15, phosphorus would reach zero long before nitrogen ran out. That it didn't is evidence for phosphorus augmentation through mineralization of parent materials in the Quitobaquito area.

Oxygen

Oxygen is perhaps the chemical parameter most diagnostic of biologic conditions in aquatic ecosystems. At all times and places where oxygen was measured at Quitobaquito during the course of this study, water was well oxygenated. Great variation existed in the set of samples however, as a result of physical attributes of the pond (e.g. stratification) and water chemistry (See Table 11).

Oxygen was measured in spring and stream subsystems only on the three 1985 sampling dates (See Table 12). At the time of sampling, oxygen was below saturation for ambient water temperature, and well below characteristic values in pondwater. Typically, spring water is anoxic or very low in oxygen. Samples taken at Quitobaquito were taken some distance from the emergence point and had obviously increased in oxygen by the time of sampling, although several were well below saturation. Oxygen increased as water flowed from the spring heads to the pond

except on 4/18/85 when spring water was already approximately 100% saturated.

Of the two processes which contribute oxygen to water, diffusion and photosynthesis, the former was probably more significant in the flowing part of the system. Evidence for this is the fact that dissolved oxygen increased as expected except when initial saturation was 100%. Net diffusion from atmosphere to water stops at 100% saturation regardless of the turbulence associated with running water. At constant temperature, dissolved oxygen at 100% saturation can only increase (through photosynthesis) or decrease (by respiration) as a result of biological activity.

While Quitobaquito Pond exhibited marked thermal stratification only on the July, 1984 sampling date, oxygen profiles indicate transient stratification at other times (Table 11). In March, 1985, the pond was never thermally stratified, yet oxygen was higher in deeper samples than at the surface. At the deepest spot in the pond (1.3 m), oxygen was 16.8 ppm at 1415 hrs, but was only 13.2 ppm at the surface. Both values were supersaturated (148 and 188% respectively), indicating a high rate of photosynthesis. The important point is that oxygen is higher in deeper strata than at the surface, indicating 1) a high rate of benthic (rather than planktonic) photosynthesis, and 2) at least a transient chemical stratification-one not apparent in the thermal profile.

Extensive samples were not taken in April 1985, and there is no evidence that the pond was stratified, nor that benthic photosynthesis was responsible for the major fraction of oxygen production. Still, oxygen saturation was over 100%, indicating that production exceeds respiration overall (See Table 11).

In July, 1985, thermal stratification was weak. Temperature at the pond surface at 1300 hrs was 33.1 $^{\circ}$C and at 0.9 m temperature was 32.6 $^{\circ}$C, a difference of just 0.5 $^{\circ}$C. Oxygen differences were dramatic however, with a 6 ppm difference at 1300 hrs between 0.1 and 0.9 m depth samples. Most of this change occurred in the last 10 cm, which exhibited a 4.8 ppm change in oxygen. At the time measurements were taken, a heavy growth of diatoms and macrophytes was present near the pond bottom. This assemblage evidently produced oxygen much faster than it could be incorporated in the water column, mixed, transported to the surface, and lost by diffusion to the atmosphere. At the 0.9 meters depth, at that date and time, oxygen was 239% saturated as compared to 158% at the surface (See Table 11).

Table 11. Dissolved oxygen, mg/l, in Quitobaquito Pond. Saturation percentages are based on temperature at time and depth and uncorrected for elevation or salinity.

DATE	TIME	DEPTH (cm)	TEMP (°C)	OXYGEN (mg/l)	PERCENT Saturation
7/26/84	1400	0.2	32.0	7.79	106
		0.7	27.5	9.13	117
7/26/84	1700	0.2	-	7.2	92
		0.7	27.6	9.13	117
7/27/84	0700	0.2	27.7	6.57	84
		0.7	-	6.22	80
3/11/85	1345	0.1	19.7	13.7	154
		0.5	19.7	13.75	155
		0.8	19.7	13.9	156
	1415	0.1	-	13.2	148
		0.1	-	13.7	154
		0.1	-	13.2	148
		1.3	-	16.8	189
	1700	0.1	19.9	14.5	164
		0.8	19.9	14.5	164
3/12/85	0905	0.1	17.4	11.4	123
		0.8	17.4	11.6	125
	1120	0.1	18.5	12.1	133
		0.8	18.5	12.3	135
4/18/85	1330	0.1	24.3	12.8	156
		0.8	24.3	12.8	156
7/30/85	1130	0.02	31.8	9.75	133
		0.1	31.8	9.6	131
		0.2	31.8	9.7	132
		0.3	31.7	10.0	136
		0.5	31.7	10.0	136
		0.6	-	10.0	-
		0.7	31.2	12.6	170
		0.8	31.8	13.4	183
		0.9	31.0	14.5	195
		0.1	33.1	11.4	158
	1300	0.5	32.8	11.8	163
		0.7	32.8	12.4	171
		0.8	32.8	12.6	174
		0.9	32.6	17.4	240

Table 12. Oxygen concentrations for Quitobaquito Spring and stream waters for various dates.

DATE	SITE	TIME	TEMP	OXYGEN	% SATURATION
			(^{o}C)	(mg/l)	
3/11/85	North Spring	1555	26.3	5.4	68
	South Spring	1546	24.8	5.4	66
	Gauge	1540	25.6	6.6	82
	Observation Pool	1520	25.4	6.95	86
	Inlet to Pond	1510	25.3	7.2	89
4/18/85	North Spring	1200	27.2	8.0	102
	South Spring	1216	26.6	8.3	105
	Gauge	1153	26.9	7.4	94
	Observation Pool	1410	26.9	7.7	98
	Inlet to Pond	1415	26.9	8.1	103
7/30/85	North Spring	1230	29.3	6.1	80
	Gauge	1230	29.7	7.0	93
	Observation Pool	1230	31.6	6.9	94

In July, 1984, oxygen showed a similar, yet less marked response. The pond was thermally stratified and oxygen was stratified and supersaturated in the afternoon. By early the next morning oxygen had dropped over 30 percentage points to well below saturation. This nighttime drop is attributable to sustained respiration of plants and animals at a time (night) when oxygen production (through photosynthesis) was nil. Interestingly, the nighttime decline in oxygen was most pronounced near the bottom of the pond, indicating that rates of benthic respiration also exceed those of the water column (See Table 11). Therefore, we can infer that biological activity in Quitobaquito Pond is predominantly benthic and is largely autotrophic (photosynthesis exceeds respiration).

Cole and Whiteside (1965) estimated gross primary production of the pond to be 0.33 mg O_2/cm_2/d based on rate of observed oxygen change in the day (an estimate of net production) and at night (an estimate of respiration). While this method is fraught with difficulties, most notable is that it fails to adjust for diffusion loss to the atmosphere, which is substantial, given the conditions of supersaturation that commonly occur. Still, daily excursion of oxygen concentration probably does bear a relationship to rate of system production. Using Cole and Whiteside's method, rates of gross primary production on the two dates for which I have the appropriate data (7/26/84 and 3/11/85) are 0.35 and 0.46 mg O_2/cm^2/d respectively. These data are in agreement with those Cole and Whiteside reported 20 years ago.

SEDIMENTS AND SHOALING

All standing waters are born to die and Quitobaquito is no exception. Since the pond is a vital resource and a critical habitat of *Cyprinidon macularius*, it undoubtedly will be maintained as an open water pond, probably by intermittent dredging. At present, evidence on sedimentation rate is circumstantial and inferential; however, my judgement is that filling is occurring very slowly. This judgement is based on the following emperical observations:

1) Original pond contours provided for a flat bottom at a depth of about 1.0 meter and steep, almost vertical sides. Cole and Whiteside (1965) report a maximum depth of 1.0 m in the pond in 1962. My measurements and a recent, extensive survey by the Park Service (Peter Bennett, personal communication) indicate that the pond retains these approximate bottom dimensions today within about 10%.

2) Lateral encroachment of macrophytes, particularly *Scirpus olneyi*, has produced an overhanging bank of plants and detritus on the periphery of the pond; however, this overhang rarely exceeds 0.5 m. The original shoreline is thus, little changed. Lateral encroachment, therefore, has also been minimal.

3) Sediment cores taken in the open water reveal the pond bottom to consist of a 4-6 cm thick carbonaceous layer intermixed with organic debris (1.4% by weight) overlying a darker, more homogeneous layer of unknown thickness, probably consisting of clay and carbonates. This observation suggests that the shoaling rate has been only 1-3 cm per decade over the history of the current pond.

4) Bottom samples taken at the northeastern end of the pond where sheetflow is most likely to deposit allochthonous, watershed-derived sediments during storms, are indistinguishable from sediments far from shore in open water. This suggests that most pond filling is traceable to a) production of organic material by aquatic plants in situ, and b) precipitation of calcium carbonate as travertine and/or marl.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

1. From a limnologic standpoint, Quitobaquito Pond and Spring system are in good condition, water quality remains good and is typical of the larger region.

2. There is little evidence that the pond has changed significantly in the 20 years that have elapsed since the system was studied by Cole and Whiteside (1965).

3. Long-term trends in spring flow are inconclusive, but should be monitored closely to detect any diminution of flow which might occur.

4. The hydrologic budget of the pond in summer is near balance. This means that a small decrease in water delivery rate may result in a decrease in the size of the pond. Decrease in delivery may result from a) diminution of spring discharge or, b) leakage of delivery system (pipe, stream) and subsequent loss via evapotranspiration through vegetation upstream from the pond.

5. While these studies are not definitive, there is no evidence that either the pond basin or dam leak. Substrates appear dense and water-impermeable; however, their thickness is unknown and future efforts (if any) to deepen the pond (e.g. by dredging) run the risk of penetrating this sealed layer.

6. Physical characteristics of the pond vary greatly in space and time. For example, light characteristics range from turbid to highly transparent. The pond stratifies for short periods of time in summer, often apparently on a daily basis (polymixis), although on some summer days it does not stratify but mixes all day.

7. Chemical characteristics of the pond vary greatly in space and time. While major ions fluctuate little, pH and oxygen range widely in response to biologic productivity. Removal of CO_2 from the water column has a substantial effect on deposition of calcium carbonate on the pond bottom. In daytime, oxygen is usually well above saturation.

8. Nitrogen (as nitrate) is highly variable and is probably the critical nutrient in the pond. It is depleted substantially as water flows from spring to pond, but never reached zero during this study. Cole and Whiteside (1965) reported complete depletion of nitrate in Quitobaquito Pond. This difference in nitrate concentration probably represents a day to day difference rather than a significant long-term trend.

9. Rate of lateral incursion of macrophytes is judged to be small over the past 20 years. Similarly, pond morphometry and the nature of sediments suggest shoaling to be similarly low (ca. 0.25 cm/year).

10. Biological productivity is only moderate in the pond and is similar to rates reported 20 years ago.

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